Improving decision making through presentation of viscoelastic tests as a 3D animated blood clot: the Visual Clot

Rössler, J ; Meybohm, P ; Spahn, D R ; Zacharowski, K ; Braun, J ; Nöthiger, C B ; Tscholl, D W

Abstract: Point-of-care viscoelastic coagulation tests are used increasingly and enable physicians to run precise whole blood coagulation diagnostics. However, the somewhat complicated and abstract presentation of results may hinder these advantages. For this reason, we developed the Visual Clot as an alternative mode of presentation for thrombelastometric data. An algorithm takes existing parameters from rotational thromboelastometry and creates a visual representation in the form of an animated blood clot named 'Visual Clot'. In a prospective international dual-centre study, 60 physicians were presented with rotational thromboelastometry results in the standard way or as a Visual Clot. They were then asked to make therapeutic decisions based on pathological findings. Overall proportion of correct therapeutic decisions was median (IQR [range] 100 (83–100 [39–100]) % for Visual Clot vs. 44 (25–50 [0–83]) % for standard rotational thromboelastometry presentation of results, $p < 0.001$. Mixed regression models yielded a mean OR (95%CI) 22.1 (13.4–36.5), $p < 0.001$ for correct decisions with the Visual Clot compared with standard rotational thromboelastometry, with an 18.7 (16.4–21.1), $p < 0.001$ second decrease in decision time. Perceived cognitive work-load was lower, and participants rated their diagnostic confidence to be higher with the Visual Clot, both $p < 0.001$. Although correct interpretation of standard rotational thromboelastometry results depended on previous rotational thromboelastometry knowledge and experience, Visual Clot interpretation did not. The Visual Clot improved rotational thromboelastometry-based therapeutic decisions, as pathologies can be recognised more rapidly and accurately. These findings underline the significance of an alternative additional visualisation technique that simplifies the interpretation of abstract standard data.

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- **Original Article**

Submitting author: Julian Rössler
Institute of Anesthesiology, University Hospital Zurich, Raemistrasse 100, 8032 Zurich, Switzerland
E-mail: julian.roessler@usz.ch, Phone: +41 (0)44 253 82 02

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J. Rössler,[1] P. Meybohm,[2] D. R. Spahn,[3] K. Zacharowski,[4] J. Braun,[5] C. B. Nöthiger,[6] D. W. Tscholl[7]

1 Resident, 3 Professor and Chairman, 6 Senior Consultant, 7 Consultant, Institute of Anesthesiology, University of Zurich and University Hospital Zurich, Zurich, Switzerland, 2 Senior Consultant, 4 Professor and Chairman, Department of Anaesthesiology, Intensive Care Medicine and Pain Therapy, University Hospital Frankfurt, Frankfurt/Main, Germany, 5 Statistician, Departments of Epidemiology and Biostatistics, Epidemiology, Biostatistics and Prevention Institute, University of Zurich, Switzerland

Correspondence to: D. W. Tscholl
E-mail: David.Tscholl@usz.ch

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Twitter: @julian_roessler

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Abstract

Point-of-care viscoelastic coagulation tests are used increasingly and enable physicians to run precise whole blood coagulation diagnostics. However, the somewhat complicated and abstract presentation of results may hinder these advantages. For this reason, we developed the Visual Clot as an alternative mode of presentation of thrombelastometric findings. An algorithm takes existing parameters from a ROTEM and creates a visual representation in the form of an animated blood clot named 'Visual Clot'. In a prospective international dual-centre study, 60 physicians were presented ROTEM results in the standard way or as a Visual Clot. They were then asked to make therapeutic decisions based on pathological findings. Overall median percentage of correct therapeutic decisions was 100% (IQR 83-100 [range 39-100]) for Visual Clot compared to 44% (IQR 25-50 [range 0-83]) for standard ROTEM result, $p<0.001$. Mixed regression models yielded an odds ratio of 22.1 (95% CI 13.4 to 36.5, $p<0.001$) for correct decision with the Visual Clot compared to the standard ROTEM, with an average 18.7 (95% CI 16.4 to 21.1, $p<0.001$) second decrease in decision time. Perceived cognitive workload was lower, and participants rated their diagnostic confidence to be higher with the Visual Clot, both $p<0.001$. While correct standard ROTEM result interpretation depended on previous ROTEM knowledge, Visual Clot interpretation did not. The Visual Clot improves ROTEM based therapeutic decisions, as pathologies can be recognized faster and more accurately. These findings underline the significance of an alternative, additional visualization technique, easing the interpretation of abstract standard ROTEM results.

Introduction

Accurate diagnostic and individualized, goal-directed treatment are integral components of modern haemostatic management [1,2]. Its development has been facilitated by the implementation of point-of-care viscoelastic coagulation monitoring with rotational thromboelastometry (ROTEM) or thromboelastography (TEG). Global haemostasis assays like ROTEM and TEG allow rapid insights into complex coagulation systems and their possible dysfunction, fill the gap left by limitations of conventional laboratory tests. The use of viscoelastic testing is recommended in European guidelines for managing trauma and severe perioperative bleeding, as it helps to reduce transfusion of allogeneic blood products [1,3]. Its benefits have been shown not only in trauma induced coagulopathy [3,4], but also in obstetric haemorrhage [5,6], cardiac surgery [7,8], transplantation [9], burn surgery [10], and neurosurgery [11]. Further, viscoelastic tests play a role in the diagnosis and treatment adjustment of haematological disorders like haemophilia, multiple myeloma or inherited afibrinogenemia [12–15]. Although the use of viscoelastic testing is already widespread, its interpretation remains to some extent difficult. It requires well trained and supervised clinical personnel, to interpret the resulting tracings and raw parameters [16]. Its growing use in different fields by sometimes less experienced personnel calls for the development of an interpretation aid, substantially easing the first contact and read of a viscoelastic result. For this reason, we developed the Visual Clot as a simpler, situation awareness-based mode of presentation of viscoelastic results. An algorithm takes existing parameters from a standard ROTEM trace and in real time creates a visual representation in the form of an animated blood clot – hence the name 'Visual Clot'. The Visual Clot was designed to enable a care provider to make the correct diagnosis as efficiently as possible, however, without making the diagnosis for the user. Thus, even with the Visual Clot, the human user remains the final decision maker and, thereby, remains in the loop of the decisions made. We hypothesize that the alternative visualization with the Visual Clot may improve ROTEM based decision-making regarding haemostatic management compared to the standard ROTEM result alone. We further hypothesize that the use of the Visual Clot leads to less perceived workload, and might improve diagnostic performance, and hence better therapeutic decisions.

Methods

The two main principles of the Visual Clot are reduction of information complexity and direct display of goal-relevant information. The Visual Clot is made up of basic components of haemostasis: Platelets, plasmatic factors and fibrin are schematically presented in an animation, where each one can be either sufficient or deficient (Figure 1). If for example the ROTEM displays an adequate maximum clot firmness (MCF) in the FIBTEM channel, representing sufficient supply and polymerization of fibrin, the Visual Clot displays yellow strings of fibrin tying the clot together. However, if the FIBTEM's MCF were too small, implying a fibrin deficiency, the yellow strings would disappear and be replaced by a placeholder in the form of a dashed line. We designed the Visual Clot according to principles of situation awareness, striving for better perception and comprehension of otherwise complicated data, which may lead to better decision making [17]. These design characteristics eliminate the need for care providers to calculate meaning from lower-level data (i.e., times, angles and amplitudes) of the raw standard ROTEM result traces.

This study was an investigator-initiated, within-subject, prospective, dual-centre trial comparing two different methods to display ROTEM results. The leading ethics committee (cantonal ethic committee of Zurich, Switzerland) reviewed the study protocol and found that this study does not require their approval (Business Administration System for Ethics Committees Number 2018-00933), as the study does not include any data of real patients nor any human material whatsoever.

We conducted the study with a total of 60 anaesthesiologists and intensivists in two large University hospitals experienced in ROTEM use: Half of the participants came from the University Hospital Zurich in Switzerland and the other half from the University Hospital Frankfurt in Germany. The selection of participants was random, as we randomly asked anaesthesiologists and intensivists during daily clinical practice in the operating room or intensive care unit to take part in the study – regardless of gender, age, degree, position or ROTEM knowledge.

After signing a confidentiality agreement and completing a short demographic survey, participants were shown four introductory slides, explaining both the Visual Clot and the standard ROTEM result.

This short instruction of the Visual Clot and the standard ROTEM result took around five minutes. The participants were then shown 12 coagulation scenarios, one after another, in randomized sequences. These 12 scenarios represented 6 different haemostatic conditions, each of which was shown twice, once as a standard ROTEM result, and once as a matching Visual Clot. Randomization of the sequences was done by Research Randomizer Version 4.0 [http://www.randomizer.org/, retrieved on December 5, 2018]. The different scenarios with their correct solutions are available in Supplementary Video 1. For each scenario, we asked the following question: 'If there are clinical signs of bleeding present, what treatment is required?' with the following possible answers: 'Fibrinogen, platelets, tranexamic acid (antifibrinolytic), protamine (to reverse heparin effect), plasmatic factors, nothing (normal result or hypercoagulable).' Multiple correct answers were possible. The scenarios were shown on an Acer Aspire V15 Nitro laptop (Acer Inc., New Taipei City, Taiwan) and the participants gave their answers on an iPad (Apple Inc., Cupertino, CA, U.S.A.) in iSurvey-based (Harvest Your Data, Wellington, New Zealand) data collection tool [18], which also measured the time to answer a question. After each of the 12 scenarios, participants self-rated their diagnostic confidence and their perceived workload.

Each Visual Clot was created from a standard ROTEM, enabling direct comparisons of matched ROTEM result and Visual Clot pairs. The algorithm used to deduct Visual Clots from artificially created ROTEM data is available as Supplementary Table 1.

The decision-making endpoint was assessed by having made a correct decision for each scenario. A decision was correct if all required and no incorrect treatments were selected. Depending on the scenario a single or multiple correct treatment were required. All other treatments were incorrect. Except in certain scenarios, where specific answers were not required, but also not incorrect (e.g. Tranexamic acid for fibrin deficiency). A detailed list of scenarios with correct, incorrect and optional answers is available in Supplementary Video 1. In each scenario the required treatments are marked green and optional treatments are marked yellow.

Time-to-decision was measured in seconds. Diagnostic confidence was assessed after each scenario on a 4-point Likert scale (0 = very unconfident, 1 = unconfident, 2 = confident, 3 = very confident). Workload was also evaluated after each scenario by the National Aeronautics and Space Administration Task Load Index (NASA-TLX). The NASA-TLX consisted of only five questions, as the otherwise sixth question on 'physical demand' was removed for the purpose of this study.

For descriptive statistics, we show medians with interquartile range (IQR) for continuous data and numbers and percentages for categorical data. Our outcome variables are the binary information about the treatment decision (correct/incorrect) and the time to decision, as well as the percentage of correct decisions for each participant and the confidence of each participant (scale from 0-3) and the perceived workload (NASA-TLX score). For an unadjusted comparison of ROTEM and Visual Clot, a nonparametric Wilcoxon test for paired data was used for the continuous outcome variables, and McNemar's test was used for the binary outcome variable. Association of self-rated ROTEM knowledge and successful decision-making was assessed by Spearman's correlation. For the comparison of ROTEM and Visual Clot with adjustment for potential confounders, mixed linear and generalized mixed linear models were used to additionally account for dependent measurements, i.e. measurements from the same participant: For the continuous variables, we calculated a linear mixed model with a random intercept per participant. For the binary outcome variable, we calculated a mixed logistic regression model with random intercept for each participant. Apart from the variable denoting the respective technology (ROTEM versus Visual Clot), all models were adjusted for the following confounders: centre, gender, experience (in years), the order in which the scenarios were looked at (e.g. being the first task, somewhere in the middle or the last one) and the respective scenario.

Analyses were carried out in R Version 3.6.1 (R Foundation for Statistical Computing, Vienna, Austria) and in GraphPad PRISM 8.1.1. (GraphPad Software Inc., CA, U.S.A.), where the figures were also created. A p-value of less than 0.05 was considered to indicate statistical significance.

For original data, please contact David.Tscholl@usz.ch.

Results

From Dec. 6. 2018 to Apr. 17. 2019, 60 anaesthesiologists and intensivists were recruited. All 60 participants rated 12 scenarios, including 6 standard ROTEM result and 6 Visual Clot, in a randomized order, resulting in 360 direct comparisons. Of those, 11 paired scenarios were excluded after completion because of an error in a scenario discovered after data collection, leading to a total number of 349 pairs.

The participants from the University Hospital Frankfurt were more experienced than the ones from the University Hospital Zurich, with a median experience of 9 years (IQR 6-12 [range 2-25]) compared to 5 years (IQR 2-10 [range 0-29]). Physicians from the University Hospital Frankfurt usually interpreted more ROTEM results in clinical routine (52 per year and physician, IQR 19-56 [range 2-100]) than at the University Hospital Zurich (20 per year and physician, IQR 7-50 [range 0-100]) (Table 1).

Overall median percentage of correct therapeutic decisions was 44 % (IQR 25-50 [range 0-83]) for standard ROTEM result, compared to 100 % (IQR 83-100 [range 39-100]) for Visual Clot (Wilcoxon test; $p < 0.001$; Figure 2). Mixed logistic regression yielded an odds ratio (OR) of 22.1 (95% confidence interval (CI) 13.4 to 36.5, $p < 0.001$) for correct decision with the Visual Clot compared to the traditional ROTEM. This means that the odds of deciding correctly were 22.1 times higher if Visual Clot was used than for standard ROTEM. The complete mixed logistic regression model is shown in Supplementary Table 2.

Participant-wise analysis showed that all but one participant was able to determine more correct answers regarding therapeutic decision-making with the Visual Clot than with the standard ROTEM result (Figure 3). Further, scenario-wise analysis showed that Visual Clot based decision-making was significantly superior to standard ROTEM result-based decision-making in 9 out of 11 scenarios. No difference in decision-making was found for the ‘Hyperfibrinolysis scenario’ and the ‘combined fibrin and plasmatic factor deficiency with hyperfibrinolysis’ (Table 2).

Median time to decision was 15 seconds (IQR 9-21 [range 4-84]) with Visual Clot, compared to 30 seconds (IQR 18-47 [range 5-142]) with standard ROTEM result ($p < 0.001$) (Figure 2). Perceived workload was also significantly lower with Visual Clot than with standard ROTEM result, with median NASA-TLX scores of 31 (IQR 16-43 [range 0-76]) and 52 (IQR 38-65 [range 1-95]) respectively ($p < 0.001$) (Figure 2). Participants rated their diagnostic confidence to be higher with the Visual Clot, (median "3 = very confident", IQR "2 = confident" to "3 = very confident" [range "1 = unconfident" to "3 = very confident"]) than with the ROTEM (median "2 = confident", IQR "1 = unconfident" to "3 = very confident" [range "0 = very unconfident" to "3 = very confident"]) ($p < 0.001$) (Figure 2). Accordingly, the generalized mixed linear model determined that using the Visual Clot leads to an on average 18.7 (95% CI 16.4 to 21.1, $p < 0.001$) second decrease in decision time, a reduction in workload by a mean of 20.1 (95 % CI 18.2 to 22.1, $p < 0.001$) points in the NASA-TLX and an increase in self-rated confidence by on average 0.8 points (95% CI 0.7 to 0.9, $p < 0.001$) on a four point Likert scale. The separate results for each study centre are shown in Supplementary Figures 1 and 2.

A Spearman's rank correlation was calculated to assess the relationship between self-rated ROTEM knowledge and correct therapeutic decisions with both the standard ROTEM result and the Visual Clot. There was a statistically significant positive correlation between self-rated ROTEM knowledge and correct therapeutic decisions in the standard ROTEM result ($r_s = 0.259$, $p = 0.046$). Correct therapeutic decisions based on the Visual Clot were independent from self-rated ROTEM knowledge ($r_s = -0.107$, $p = 0.42$) (Figure 4).

To validate the Visual Clot, we calculated the inter-rater reliability of all seven different animations used in the Visual Clot to represent different haemostatic conditions. The inter-rater-reliability of each of the seven animations or haemostatic conditions was > 95% (Supplementary Table 3).

Discussion

Analysing 349 within-subject comparisons of therapeutic decisions after Visual Clot and standard ROTEM based presentation of the results, we found that all but one participating physician was able to make more correct decisions with the Visual Clot - regardless of previous knowledge and experience with ROTEM technique. Overall, Visual Clot resulted in 100% correct therapeutic decisions while standard ROTEM resulted only in 44 %. This increase in correct decision-making was accompanied by faster decision times, and lower perceived workload. Participants were also more confident in their decision. We adjusted for possible confounders in a linear mixed model or a mixed logistic regression model, both using a random intercept for each participant to account for dependent observations. These models determined that by using the Visual Clot the odds of a correct therapeutic decision are increased by a factor of more than twenty, with the raters being about 18 seconds faster in coming to a decision.

To the best of our knowledge, this is the first study evaluating an alternative visualization technique for ROTEM trace results. However, avatar based representation of patient data has been shown to be beneficial in vital sign monitoring [19,20], as the perception of vital sign information was improved by presenting patient status as an animated patient avatar (i.e. improved recognition, greater confidence and lower workload) [19]. Both the patient avatar and Visual Clot technologies are reasonably similar, as both present medical data in the form of an animated avatar. One represents a patient and its vital sign, whereas the Visual Clot represents a blood clot and the preceding coagulation. Research into avatar based monitoring found it to enable quick situation recognition and to be generally regarded by users as intuitive, easy to learn as well as very helpful [21]. These qualities appear to be present in the Visual Clot as well, considering that all participants were first time users for Visual Clot and achieved high inter-rater-reliability.

Objective, experience dependent and subjective, self-rated ROTEM knowledge dependent correlation analysis found positive associations between previous ROTEM experience and self-rated ROTEM knowledge and the ability to correctly interpret standard ROTEM results. However, no

correlation was found for the Visual Clot, where all participants regardless of ROTEM knowledge score and self-rated ROTEM knowledge showed similar results. While participants were used to interpret ROTEM as part of their clinical routine, no participant had seen the Visual Clot before taking part in this study. This supports the idea that avatar-based graphics are easy to understand and to learn, while the more complicated traditional ROTEM display requires more learning efforts and more practice. While more experienced ROTEM users also benefited from using the Visual Clot, beginners do benefit in particular. Accessibility to novel and unexperienced users is a known trait of avatar based monitoring [21].

The superior performance of the Visual Clot design may be explained by its situation awareness based, user-centred design, facilitating neurophysiological visual processes. The goal of situation awareness-based design is to enable efficient human decision making, i.e., decisions that are accurate, quick, confident and require a low cognitive effort [17]. For example, in a situation with low thrombocytes, the thrombocytes in the Visual Clot are absent. In the conventional ROTEM traces, the decision-maker must first remember in which channels to look and what to look for (in this case, reduced maximum clot firmness in INTEM and EXTEM channels). According to logic, an easily understandable model preserves a logical commonality with the reality it mirrors [22]. For the Visual Clot, we designed a simplified blood clot containing simplified haemostasis components that may either be present or absent in a given situation. In the Visual Clot image, the level of abstraction of the raw ROTEM data is increased [23]. The need to compile a mental "picture", piece by piece, from low-level data is replaced by a look at an unambiguous image of the clotting situation. This image in avatar based monitoring is so clear, that it is even recognizable by peripheral vision alone [24]. Furthermore, the design of the Visual Clot provides a high degree of visual salience. The complexity of simultaneously identifying targets in one's visual field makes it a difficult neurophysiological task [25]. Thus, humans restrict complex object recognition to a small area or a few objects at any one time, with a focus on visually salient stimuli [26]. While visual salience is dependent on many factors, an animated object has higher salience than abstract tracings. These principles make the Visual Clot

and especially its patterns easily recognizable. Not surprisingly, hyperfibrinolysis was the only scenario in which decision-making was very good with both techniques the Visual Clot and standard ROTEM displays. Hyperfibrinolysis displayed by standard ROTEM is a unique fusiform object that can easily be diagnosed at a first glance. In this special condition, the Visual Clot had no additional advantage.

While the benefits of improved decision making are clear, the reduced cognitive workload and greater diagnostic confidence are also relevant because both lessen psychological stress. Stress drains cognitive resources and may thus reduce information processing capacity [27,28]. This can impair decision-making and worsen performance [29,30].

In this study, we created an algorithm to generate a Visual Clot from a ROTEM from standard cut-off values, as well as clinical research into pathological thresholds for ROTEM. For this purpose, we chose the following ROTEM thresholds for the Visual Clot to register a pathology: INTEM-CT greater than 240 seconds, EXTEM-CT greater than 100 seconds, EXTEM-MCF less than 40 mm, and FIBTEM-MCF less than 9 mm [31,32]. The algorithm accounts for multiple scenarios where certain thresholds may differ depending on other pathological values. As thresholds for haemostatic intervention are often specified in local standard operating procedures, consumers should be able to define their own thresholds for changes in Visual Clot in a market-ready product.

In daily clinical practice the Visual Clot is not supposed to replace standard ROTEM results but is meant to complement it in a way, where each health care professional can adapt the use of the Visual Clot individually to their needs.

Our study had some limitations. The interpretation of ROTEM and Visual Clot took place in a testing environment by using simulated data. Therefore, it may be possible that the results of our study have exaggerated a potential real-world effect. However, ROTEM traces from daily clinical work, are often less pronounced and would be more difficult to assess correctly. To avoid any ambiguity, we opted to use artificially created ROTEMs. This represents an ideal situation for traditional ROTEM traces and

thus our study might also underestimate the true difference between traditional ROTEM traces and Visual Clot. Given the strength and consistency of the results, an adequate translation into real world effects is highly probable. Further, the scenarios were independent of clinical cases. Participants had the information that the ROTEM and Visual Clot fit the associated clinical picture, but in clinical practice interpretation of ROTEM is always case dependent. In the future, simulator-based studies may show if therapeutic benefit exists in a more clinical environment by expanding simulation and embedding the Visual Clot into clinical scenarios. On the other hand, this simulation method guaranteed that there was no influence on the interpretation of the findings by other, clinical factors. The design enabled us to show the sole effect of our novel technology in this first ever study on the Visual Clot.

The study also had particular strengths. The international, dual-centre design makes the local effects unlikely. The within-subject design increases internal validity and the sample size adequately powered the analyses.

The 3D Visual Clot improves therapeutic decisions based on viscoelastic testing, as pathologies can be recognized more accurately, faster, with greater confidence and reduced perceived workload. These findings warrant further clinical testing of this simple, situation awareness-based visualization, and analysis of its impact on the still young practice of point-of-care coagulation monitoring.

Authorship Contributions

JR, DRS, CBN and DWT contributed to the study design. JR and DWT completed the collection of data in Zurich. JR, PM, CBN and DWT completed the collection of data in Frankfurt. JR, JB and DWT did the data analyses. All authors contributed to interpretation of the data. JR wrote the first draft of the manuscript. JR and DWT created the figures. All authors provided critical revisions to the manuscript before seeing and approving the final version.

Disclosure of Conflicts of Interest

The University of Zurich owns the intellectual property rights to the technology described in this manuscript and registered “Visual Clot” as a trademark. As inventors, the authors D.W.T., D.R.S, and C.B.N. may receive royalties in the event of commercialization.

Julian Rössler has no conflicts of interests to declare.

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Appendices

Appendix 1 – Supplementary Material

Appendix 2 – Supplementary Video 1: Instructional video to the Visual Clot

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Table 1 Study and participant characteristics. Values are medians (IQR [range]) or number (proportion).

Number of participants	60	
Number of different ROTEM cases rated	11	
Number of direct comparisons between ROTEM and Visual Clot	349	
	Zurich	**Frankfurt**
Number of participants at study site	30	30
Sex; female (%)	14 (47)	9 (30)
Participants position		
Senior physician (%)	14 (47)	21 (70)
Resident physician (%)	16 (53)	9 (30)
Anaesthesia experience of physicians; years	5 (2-10 [0-29])	9 (6–12 [2-25])
ROTEMS interpreted by physicians per year; number	20 (7-50 [0-100])	52 (19-56 [2-100])
Duration per data collection; minutes	22 (20-26 [11-45])	20 (17-22 [12-34])

Table 2: Scenario based results for both study centres. Values are medians (IQR [range]) or number (proportion). Perceived diagnostic confidence: 0=very unconfident, 1=unconfident, 2=confident, 3=very confident. Perceived workload: NASA=National Aeronautics and Space Association, TLX= Task Load Index.

Case	ROTEM	Visual Clot	P-value
1. Normal (10min)			
• Correct decisions	17/24 (71)	24/24 (100)	0.023
• Time to decision in seconds	49 (27-65 [16-109])	12 (7-19 [4-27])	<0.001
• Perceived diagnostic confidence	2 (1-2 [0-3])	3 (3-3 [2-3])	<0.001
• Perceived workload NASA TLX score	58 (39-69 [0-90])	25 (11-35 [0-45])	<0.001
2. Normal (60min)			
• Correct decisions	21/36 (58)	34/36 (95)	<0.001
• Time to decision in seconds	18 (11-37 [7-103])	8 (6-12 [4-36])	<0.001
• Perceived diagnostic confidence	2 (1-3 [0-3])	3 (2-3 [1-3])	<0.001
• Perceived workload NASA TLX score	45 (28-55 [0-75])	25 (5-35 [0-65])	<0.001
3. Fibrin deficiency (10min)			
• Correct decisions	5/24 (21)	22/24 (92)	<0.001
• Time to decision in seconds	49 (38-56 [12-116])	19 (15-34 [9-57])	<0.001
• Perceived diagnostic confidence	1 (1-2 [0-3])	2 (2-3 [1-3])	<0.001
• Perceived workload NASA TLX score	55 (46-67 [20-85])	33 (10-40 [0-65])	<0.001
4. Platelet deficiency (10min)			
• Correct decisions	8/36 (22)	32/36 (89)	<0.001
• Time to decision in seconds	34 (22-46 [9-103])	13 (8-18 [6-23])	<0.001
• Perceived diagnostic confidence	1 (1-2 [0-3])	3 (2-3 [1-3])	<0.001
• Perceived workload NASA TLX score	50 (41-65 [20-95])	25 (15-35 [0-55])	<0.001
5. Plasmatic coagulation factor deficiency (60min)			
• Correct decisions	10/36 (28)	31/36 (86)	<0.001
• Time to decision in seconds	27 (15-38 [5-85])	20 (15-26 [5-47])	0.008
• Perceived diagnostic confidence	2 (1-2 [0-3])	2 (2-3 [1-3])	<0.001
• Perceived workload NASA TLX score	50 (35-65 [15-80])	43 (19-53 [0-70])	<0.001
6. Hyperfibrinolysis (60min)			
• Correct decisions	13/18 (72)	16/18 (89)	0.37
• Time to decision in seconds	35 (22-44 [10-64])	13 (11-16 [6-48])	<0.001
• Perceived diagnostic confidence	2 (1-2 [1-3])	2 (2-3 [1-3])	<0.001
• Perceived workload NASA TLX score	56 (45-65 [14-75])	28 (15-37 [8-55])	<0.001
7. Heparin effect (60 min)			
• Correct decisions	10/24 (42)	22/24 (92)	0.002
• Time to decision in seconds	45 (29-68 [8-135])	16 (13-26 [8-42])	<0.001
• Perceived diagnostic confidence	2 (1-2 [0-3])	3 (2-3 [1-3])	<0.001
• Perceived workload NASA TLX score	53 (40-65 [15-75])	32 (14-44 [0-50])	<0.001
8. **Hypercoagulability (10 min)**			
• Correct decisions	28/36 (78)	36/36 (100)	0.013
• Time to decision in seconds	16 (9-36 [5-139])	10 (6-16 [4-38])	<0.001
• Perceived diagnostic confidence	2 (1-3 [0-3])	3 (2-3 [1-3])	<0.001
• Perceived workload NASA TLX score	43 (15-55 [0-75])	20 (5-40 [0-70])	<0.001
9. Platelet deficiency masked by high fibrin (60 min)			
• Correct decisions	2/60 (3)	57/60 (95)	<0.001
• Time to decision in seconds	25 (13-37 [6-142])	15 (10-22 [5-84])	0.001
• Perceived diagnostic confidence	2 (1-3 [0-3])	3 (2-3 [1-3])	<0.001
• Perceived workload NASA TLX score	50 (39-60 [0-90])	30 (15-40 [0-70])	<0.001

10. Fibrin, platelet and plasmatic factor deficiency (60min)			
• Correct decisions	9/19 (47)	17/19 (89)	0.027
• Time to decision in seconds	30 (24-43 [12-75])	23 (19-34 [9-79])	0.003
• Perceived diagnostic confidence	2 (1-2 [1-3])	2 (2-3 [1-3])	0.008
• Perceived workload NASA TLX score	60 (40-65 [30-83])	35 (15-55 [3-65])	<0.001
11. Fibrin and plasmatic factor deficiency with hyperfibrinolysis (60min)			
• Correct decisions	17/36 (47)	27/36 (75)	0.052
• Time to decision in seconds	28 (19-43 [10-102])	21 (16-30 [10-80])	0.002
• Perceived diagnostic confidence	2 (1-2 [0-3])	2 (2-3 [1-3])	<0.001
• Perceived workload NASA TLX score	55 (36-67 [10-85])	35 (15-46 [5-75])	<0.001

Figures:

Figure 1: The Visual Clot. (A) This scanning electron micrograph of a blood clot depicts red blood cells and platelets enmeshed in a fibrinous matrix. The Visual Clot was modelled after this image. This image has been released into the public domain by its author Janice Haney Carr (retrieved from the Centers for Disease Control and Prevention's Public Health Image Library on May 17th 2019; Image ID: 7308). (B) The different animations representing basic haemostatic components. (C) A normal Visual Clot, with no pathologies. (D) The Visual Clot with fibrin, factor, platelet deficiency and hyperfibrinolysis. A HEPTEM was run, but no heparin effect was found. The bleeding effect occurs, if anything is abnormal.

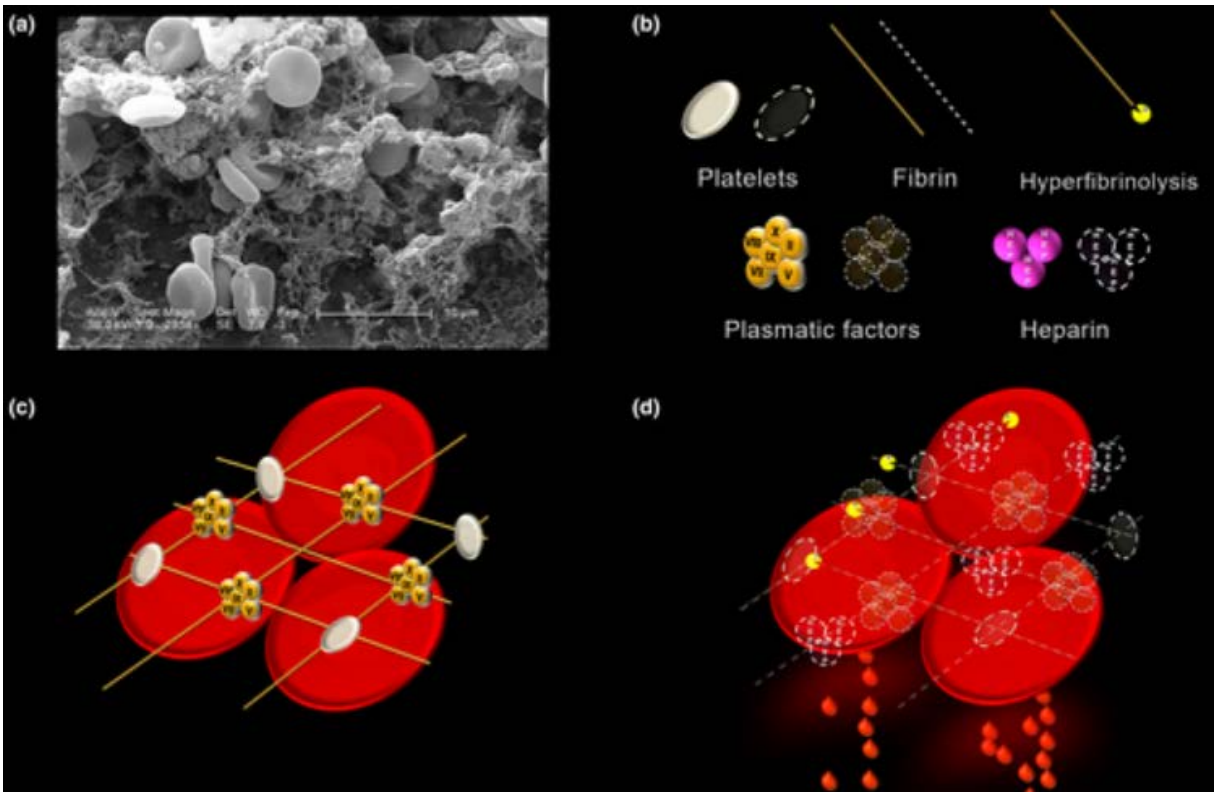

Figure 2: Example scenario of a ROTEM with a corresponding Visual Clot. The scenario displays a plasmatic factor deficiency, as shown by the prolonged clotting time (CT) in the (A) ROTEM EXTEM and INTEM channel or the missing plasmatic factors in the (B) Visual Clot. This scenario would be answered correctly by selecting "plasmatic factors" as a treatment and nothing else.

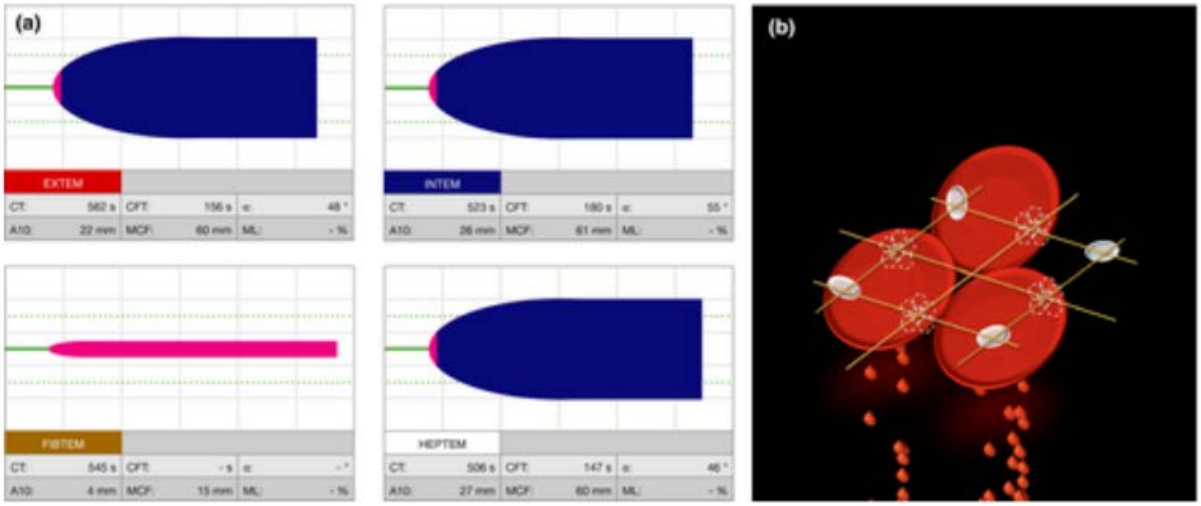
(a)
EXTEM
CT: 562 s CFT: 156 s α: 48 °
A10: 22 mm MCF: 60 mm ML: - %
INTEM
CT: 523 s CFT: 180 s α: 55 °
A10: 26 mm MCF: 61 mm ML: - %
FIBTEM
CT: 545 s CFT: - s α: - °
A10: 4 mm MCF: 15 mm ML: - %
HEPTEM
CT: 506 s CFT: 147 s α: 46 °
A10: 27 mm MCF: 60 mm ML: - %
(b)

Figure 3: Overall group differences between the standard ROTEM display and the Visual Clot. Box plots are medians with interquartile range, whiskers are 5-95 percentile, dots are individual outliers. Perceived diagnostic confidence: 0=very unconfident, 1=unconfident, 2=confident, 3=very confident. Perceived workload: NASA=National Aeronautics and Space Administration, TLX= Task Load Index. N for decision making = 60, N for time to decision, perceived diagnostic certainty, perceived workload = 349.

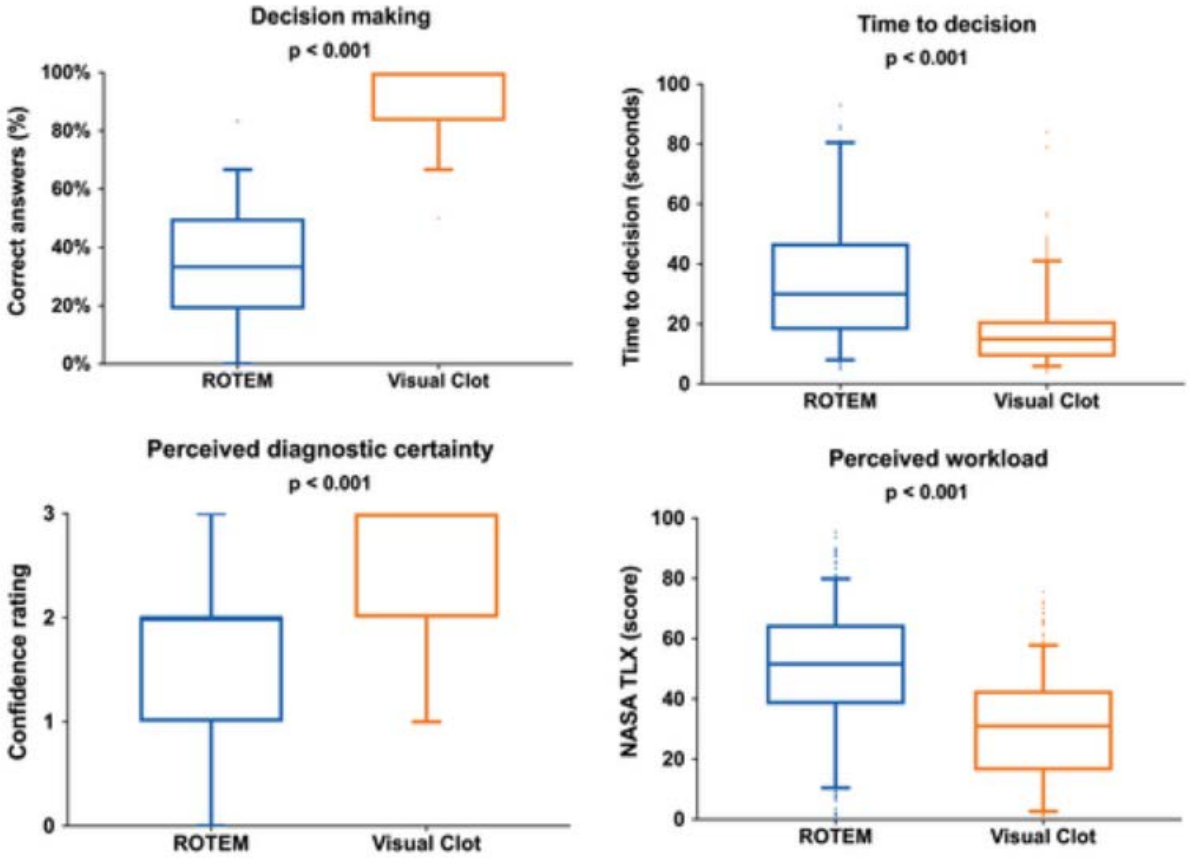

Figure 4: Decision-making on an individual participant level. Percentage of correct answers for each of the 60 participants ranked on the X-axis from left to right according to achieved percentage of correct decisions with conventional ROTEM.

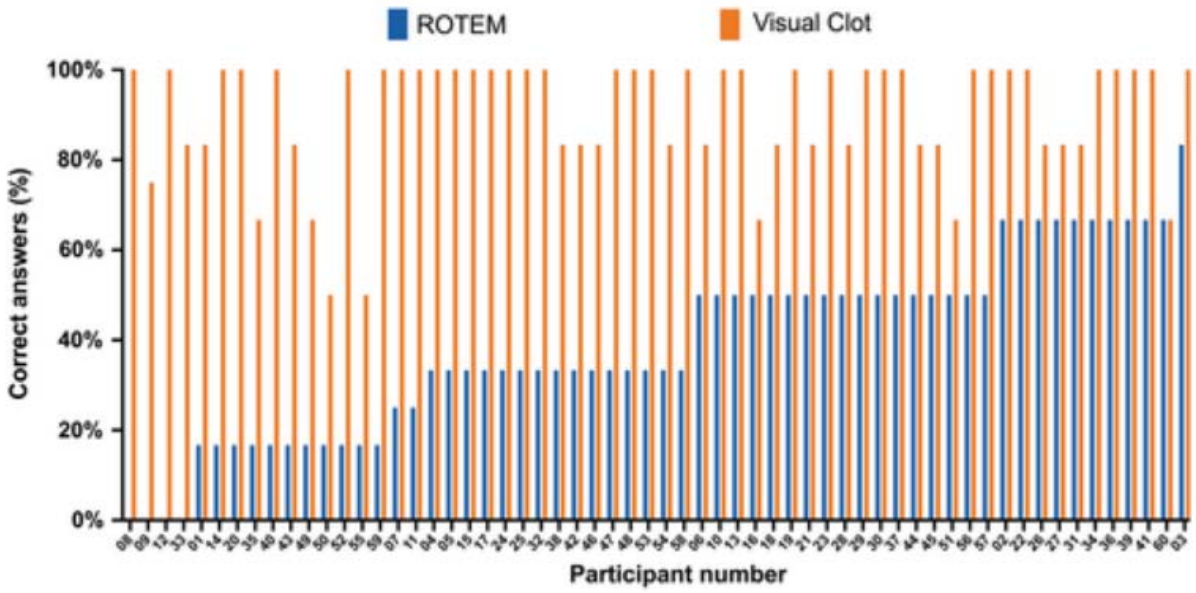

Figure 5: Spearman's correlation of self-rated ROTEM knowledge and correct decisions for each participant.